THE AEROSPACE CORPORATION

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5/22/03

# Modern Techniques in Sounder Data Compression

For GOES-R Program

Electronic Systems Division

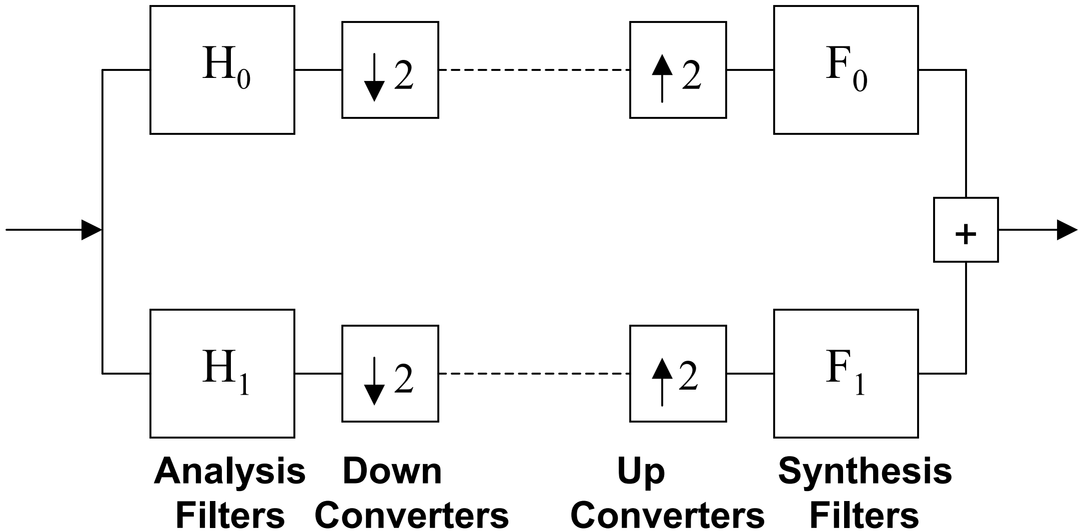
# State-of-the-Arts

- **Biorthogonal Wavelet Transform (BWT) – has been adopted in JPEG2000 for still image data compression – for both lossy and lossless data compression.**
- **Cosine Modulated Subband Filterbanks – e.g. Modulated Lapped Transform (MLT), Modified Discrete Cosine Transform (MDCT), Local Cosine Transform – for lossy data compression only.**
  - ➢ **MDCT has been used in MPEG – MP3 and AC-3 for high quality audio data compression.**
  - ➢ **Aerospace has patented MLT for high quality lossy image compression.**
  - ➢ **Aerospace has invented lossless MLT.**

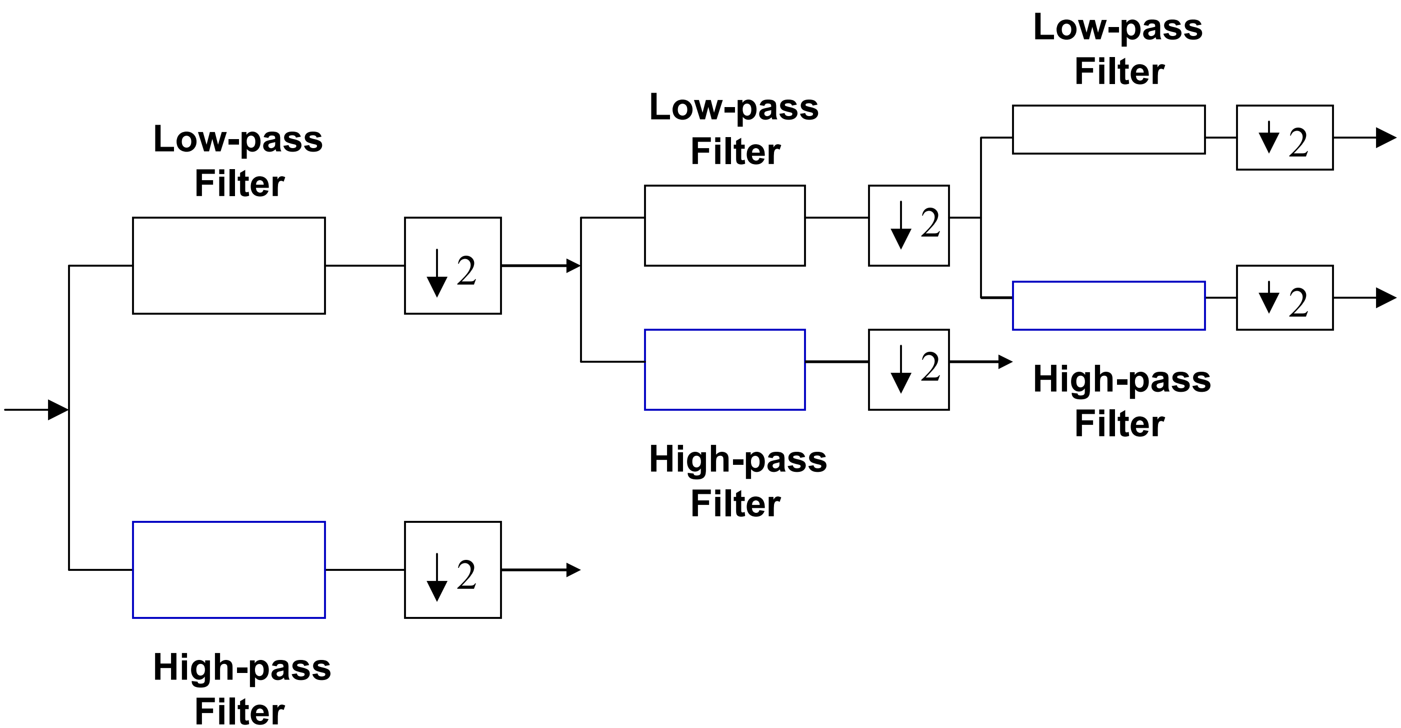
# Agenda

- 3D lossy and lossless data compression for ABS simulated AIRS data and real HES data using the Biorthogonal Wavelet Transform (BWT).
- Comparison of BWT to Modulated Lapped Transform (MLT) method.
- Development of the Hybrid Orthogonal Transform (HOT).
- Future work

# Single Layer Biorthogonal Wavelet Transform



# Three Layer Biorthogonal Wavelet Transform
# ( only the analysis filters are shown below )

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# 3D Lossless Data Compression on Simulated AIRS Data

- Have done 3D lossless data compression, using BWT, for ABS simulated long-wavelength AIRS data.
  - For noisy data the compression ratio is 2.04
  - For noise-free data the compression ratio is 3.36

# 3D Lossy Data Compression on Simulated AIRS Data

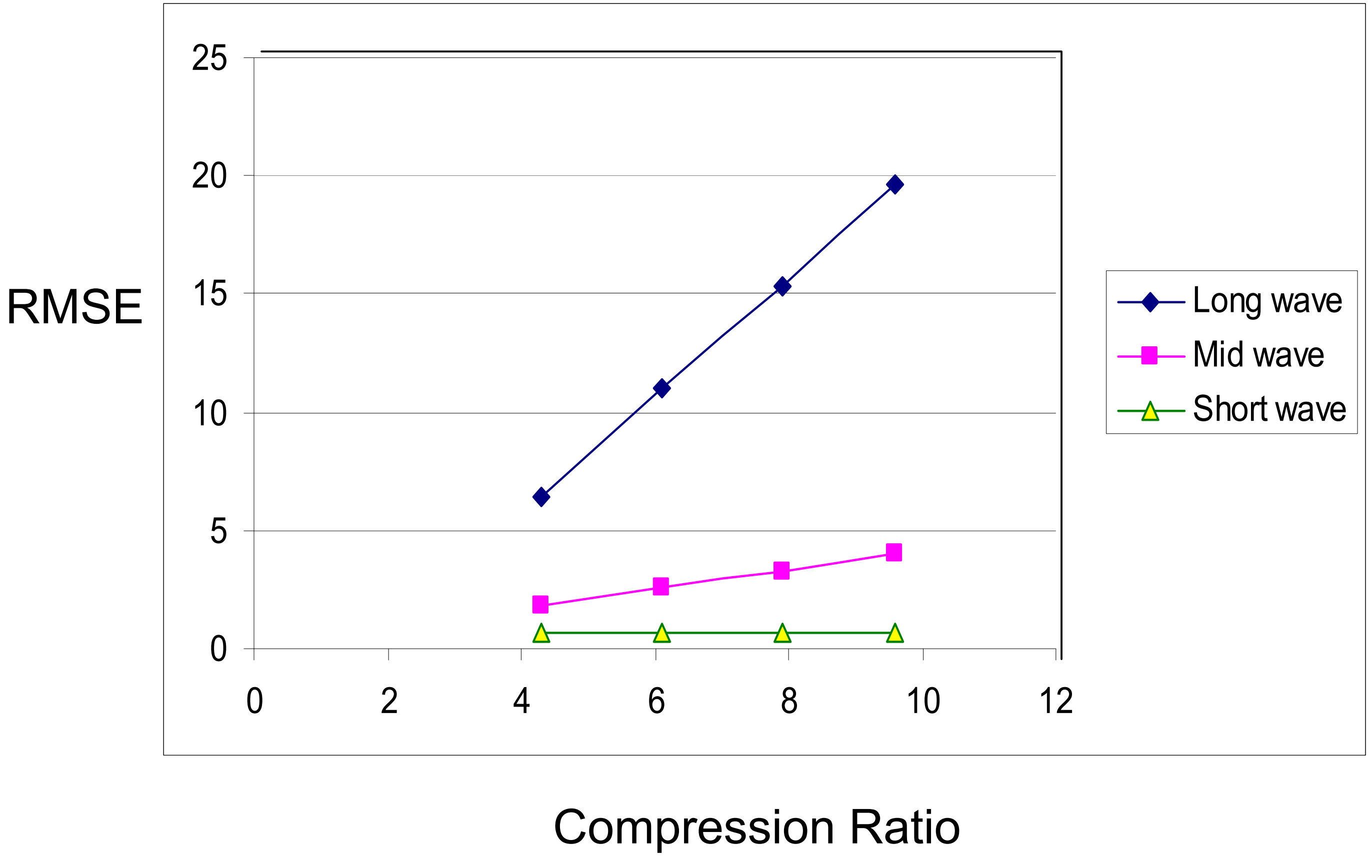
- **Have finished 3D lossy data compression, using BWT, for ABS simulated long-wavelength, mid-wavelength, and short- wavelength AIRS data.**
- **The results are shown in the following slides.**
- **Due to the high contrast of the long-wavelength data, the compression ratios have been kept below 10 for reasonably small errors (1.1%).**
- **SSEC in University of Wisconsin has done the retrieval analysis on these results.**

# Image Quality Metrics

- **Global** Quality Measure:
  - Root-Mean-Squared Error (**RMSE**)
  - Peak Signal-to-Noise Ratio (**PSNR**)
  - $PSNR = 20 \, Log_{10}(255 / RMSE) \quad dB$
- **Local** Quality Measure:
  - Peak Absolute Error (**PAE**)
  - $PAE = Max|orig(p_i) - rec(p_i)| \quad$ for all i

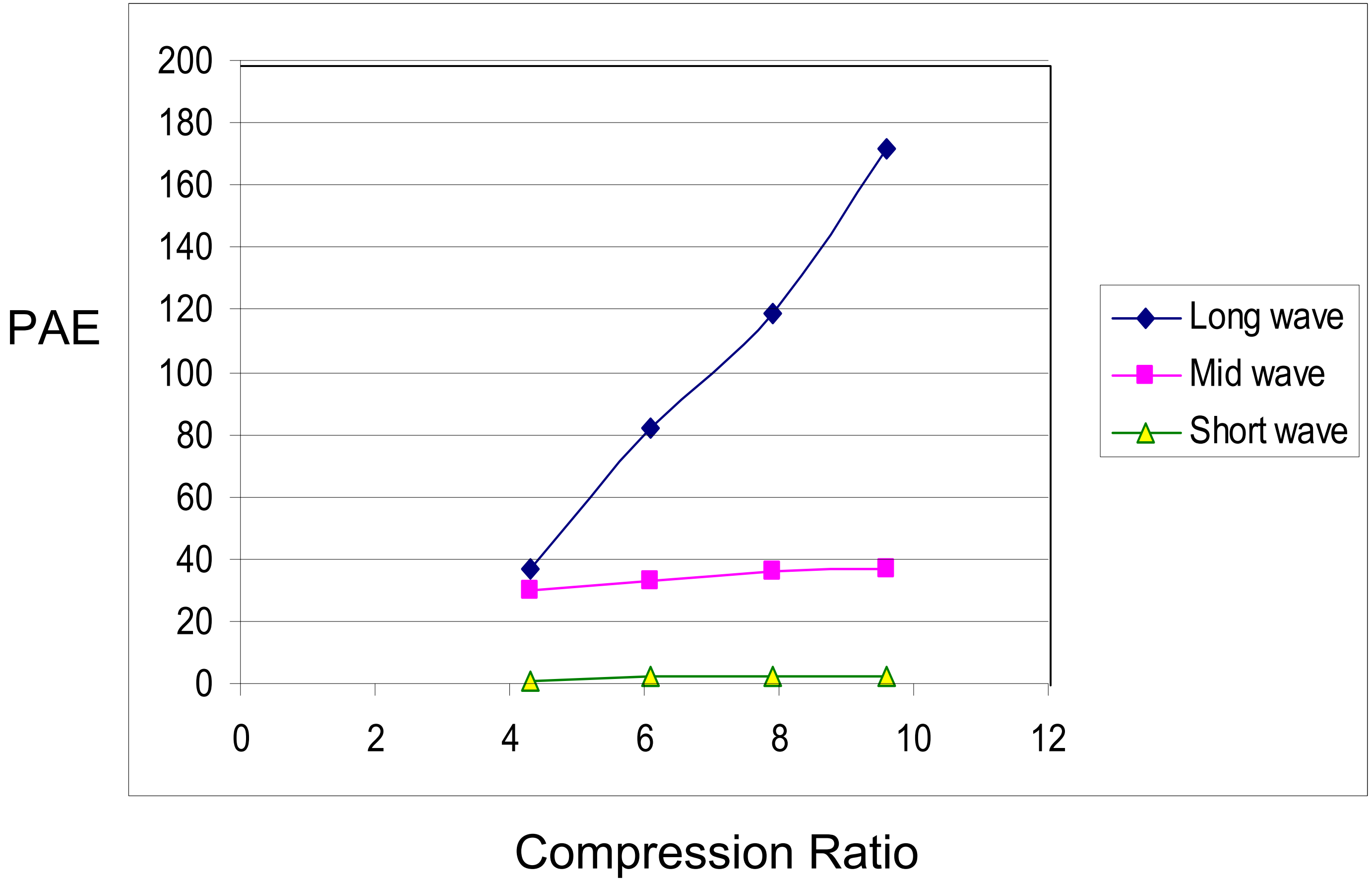
# 3D Lossy Compression Using BWT

## For Simulated AIRS Data (The maximum RMSE ~ 0.12%)



# 3D Lossy Compression Using BWT

## For Simulated AIRS Data (The maximum PAE ~ 1.1%)

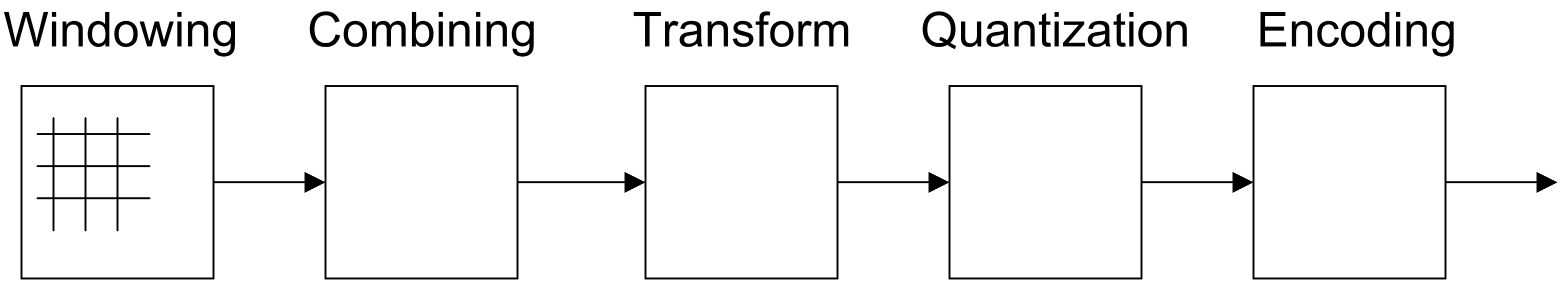


# 3D Lossy Data Compression on Real HES Data

## Compression ratio for all LW, MW, and SW was set to 4.4

| | RMSE | PSNR(dB) | PAE |
|---|---|---|---|
| LW | 19.43 | 58.52 | 402 |
| MW | 6.26 | 68.35 | 148 |
| SW | 27.00 | 55.65 | 16290 |

# Principles of MLT



# Comparison of MLT to BWT

16:1 BWT

16:1 MLT

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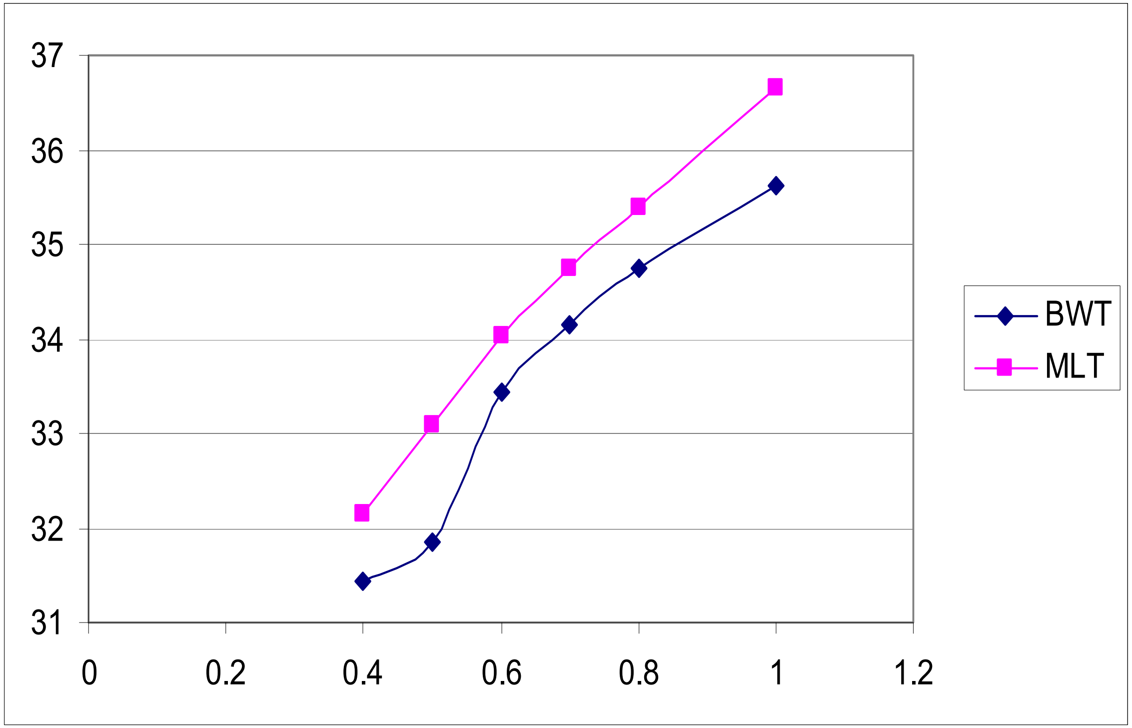
# Comparison of MLT to BWT

## For Test Image: Goldhill

PSNR in dB




Bitrate

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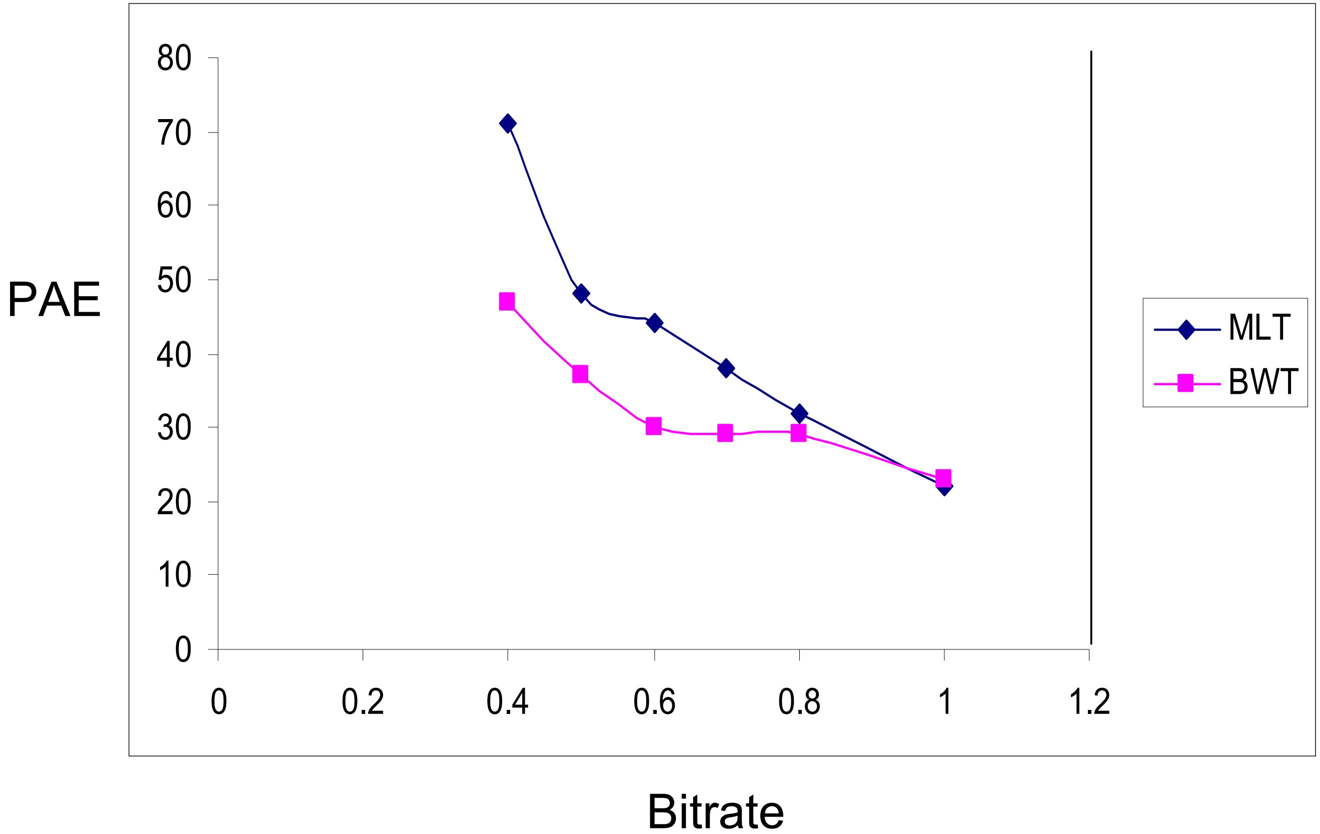
# Comparison of MLT to BWT

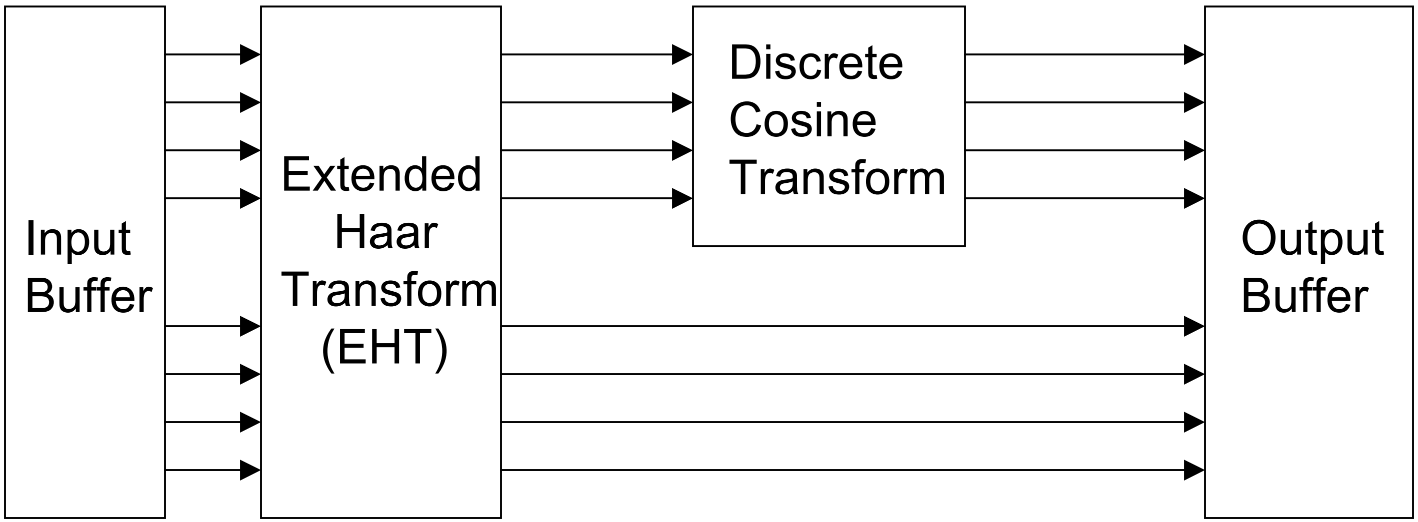
## For Test Image: Goldhill



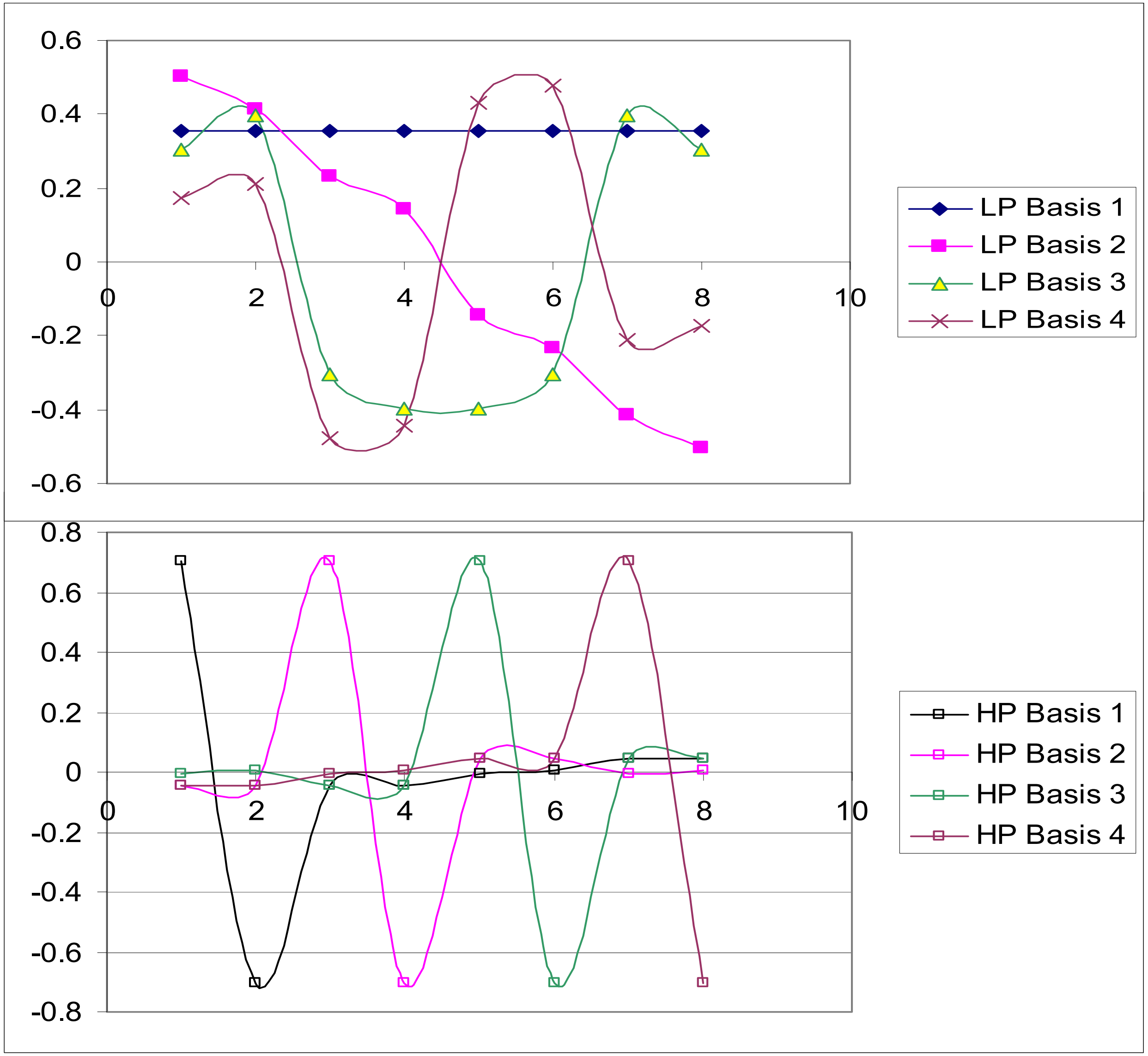
# Recent Inventions

- **The lossless Discrete Cosine Transform (DCT)**
- **The lossless Modulated Lapped Transform (MLT)**
- **The lossy and lossless Extended Haar Transform (EHT)**
- **The lossy and lossless Hybrid Orthogonal Transform (HOT)**

# Hybrid Orthogonal Transform (HOT)



# Basis Functions of HOT



# Comparison of HOT with DCT

| original | DCT output | HOT output | |
|---|---|---|---|
| 14 | 231.93 | 231.93 | low-frequency components |
| 75 | -67.50 | -67.88 | |
| 76 | -19.67 | -12.94 | |
| 87 | -30.46 | -12.45 | |
| 89 | -13.44 | -40.34 | high-frequency components |
| 97 | -20.28 | -3.14 | |
| 99 | -8.69 | -2.86 | |
| 119 | -11.33 | -9.50 | |

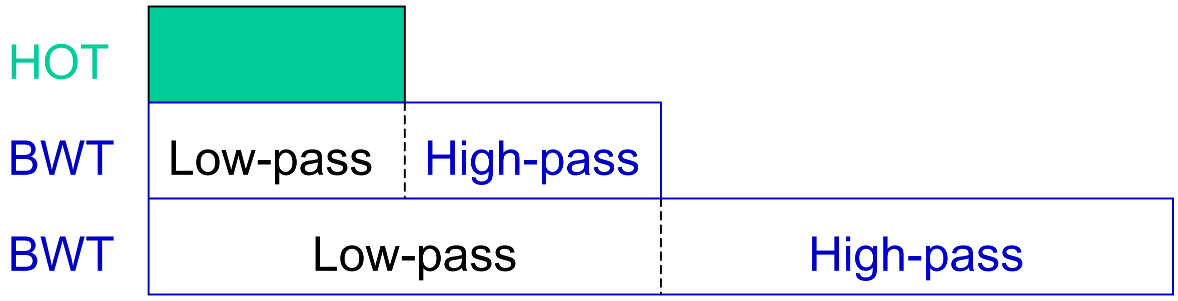
The low-frequency HOT components drop off faster than DCT
The high-frequency HOT components have well-defined locality than DCT

# Advantages of HOT

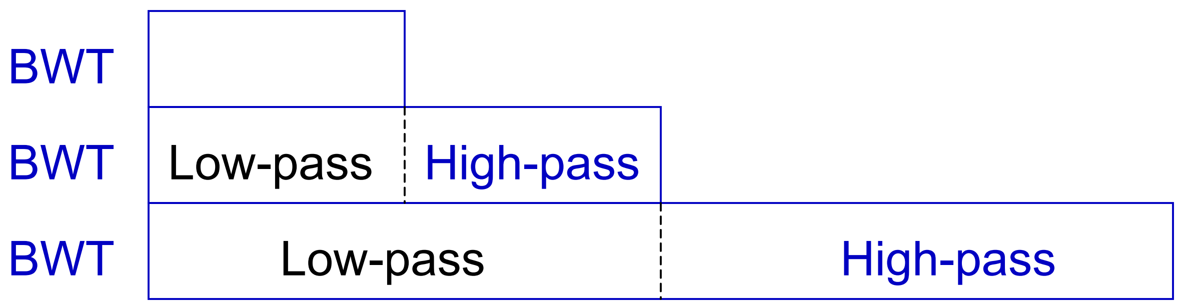
- **Long sought after transform for both lossy and lossless data compression applications.**
- **The low-pass bases can achieve as much as energy compaction as the Discrete Cosine Transform (DCT).**
- **The high-pass bases have as much space localization as the Haar Wavelet Transform.**
- **The HOT pyramid outperforms the Biorthogonal Wavelet Transform (BWT) pyramid being adopted in JPEG 2000.**

# Multiple Resolution Pyramid Layers

New Transform Pyramid (HOT Pyramid)




JPEG2000 Transform Pyramid (BWT Pyramid)

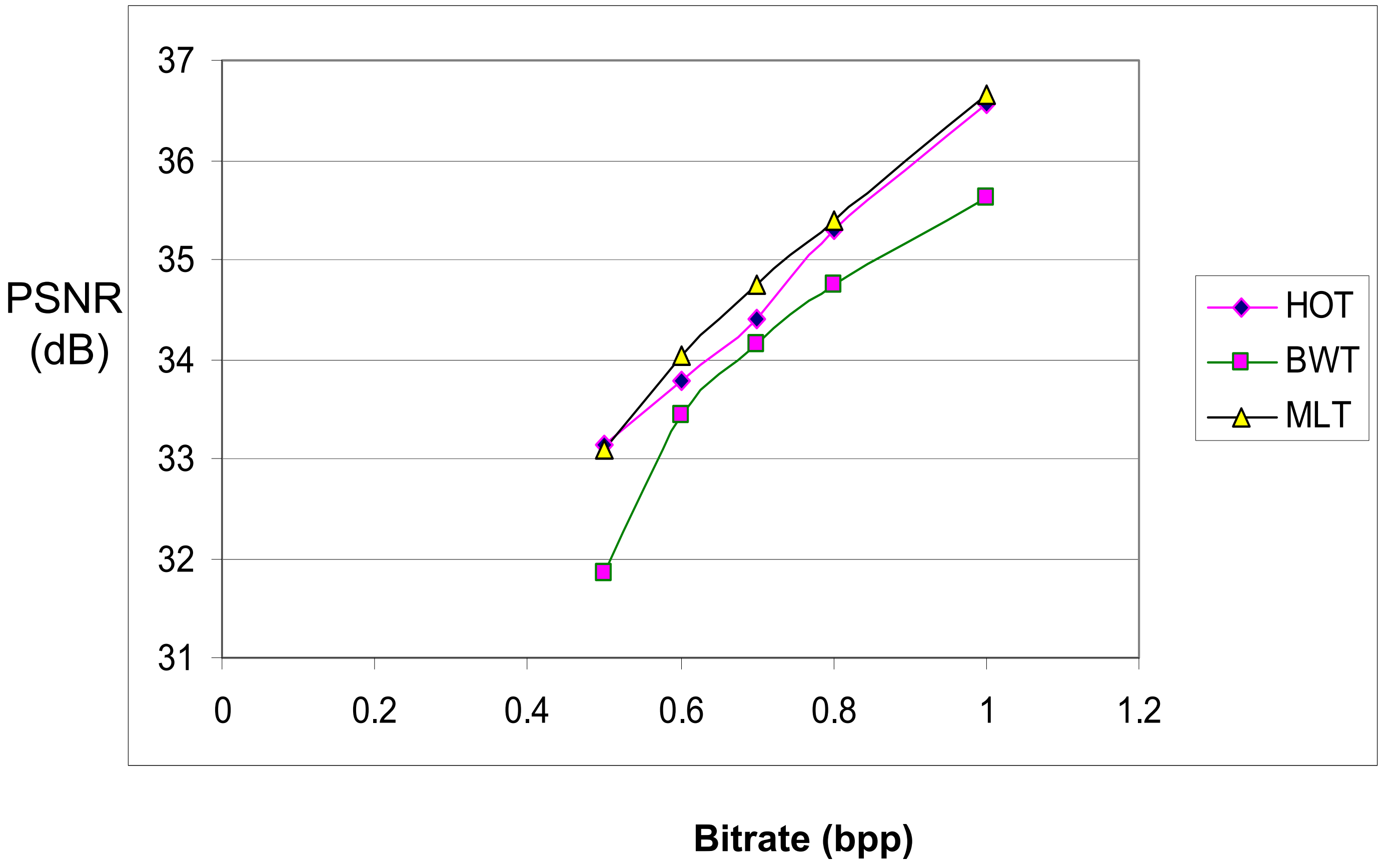


# Comparison of HOT Pyramid to BWT Pyramid

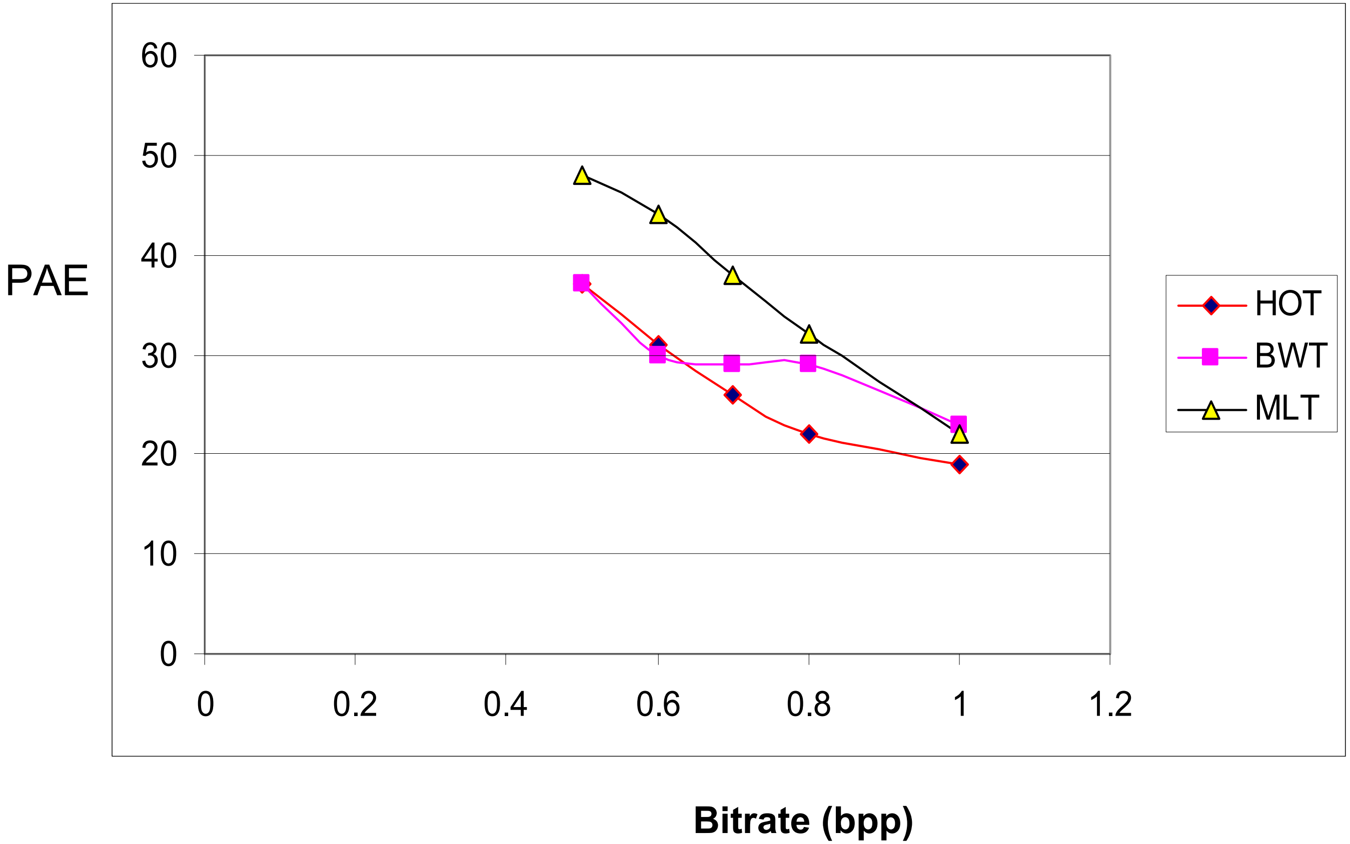
16:1 BWT

16:1 HOT

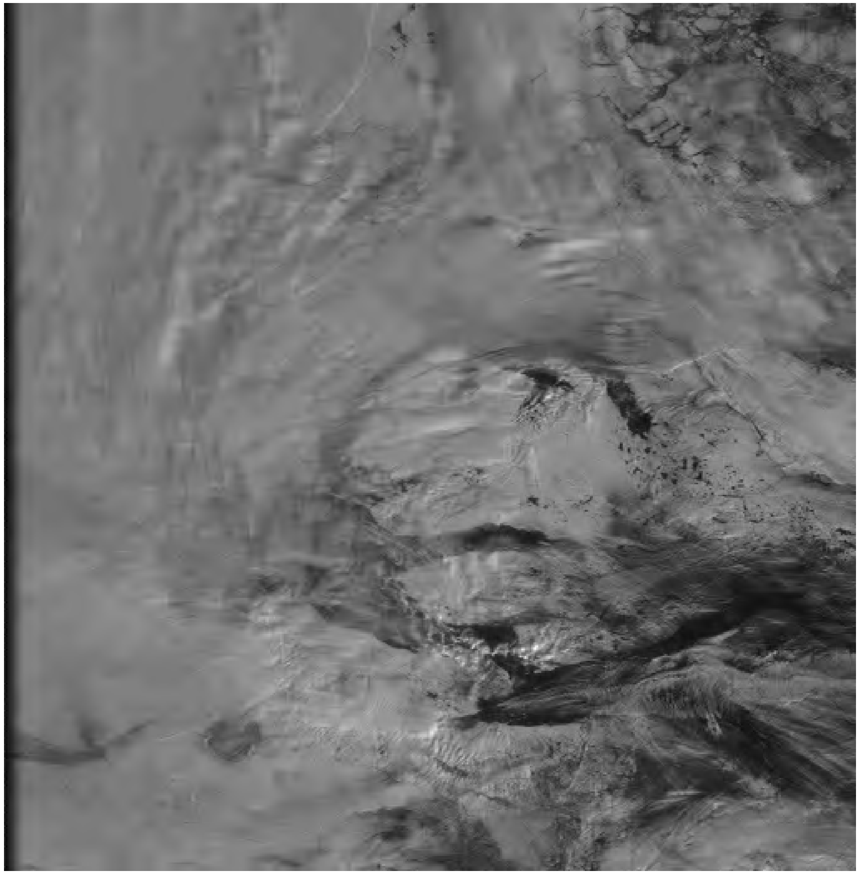
# Comparison of HOT and BWT Pyramids to MLT (Sample image: Goldhill)



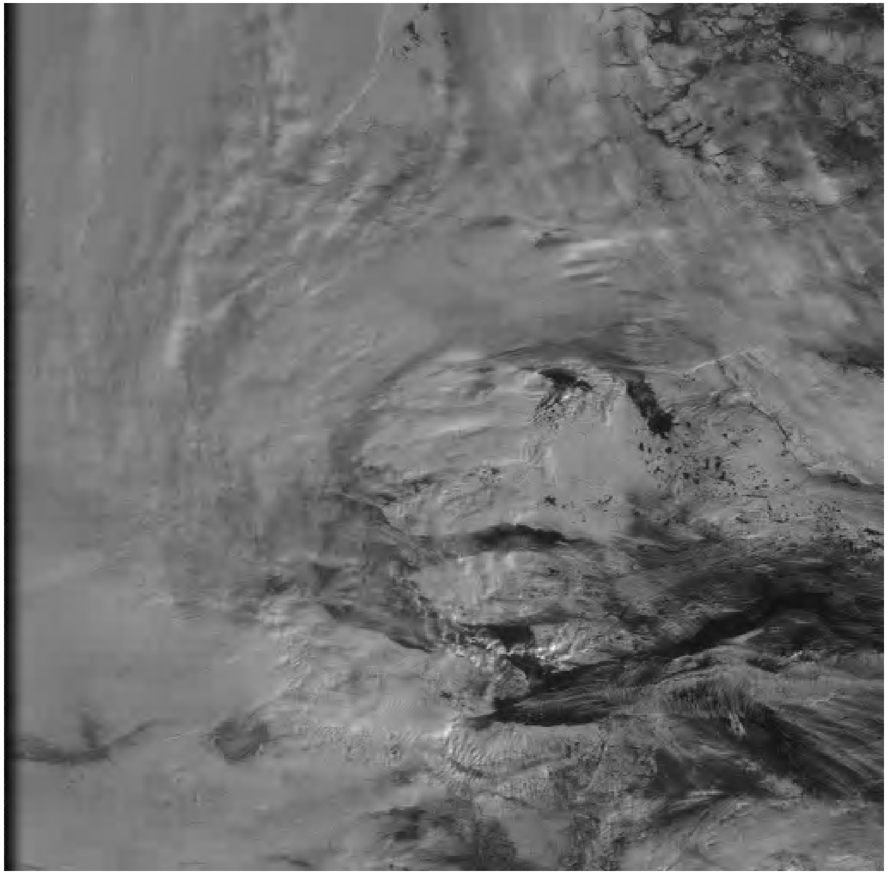
# Comparison of HOT and BWT Pyramids to MLT (Sample image: Goldhill)



# Comparison of HOT Pyramid to BWT Pyramid

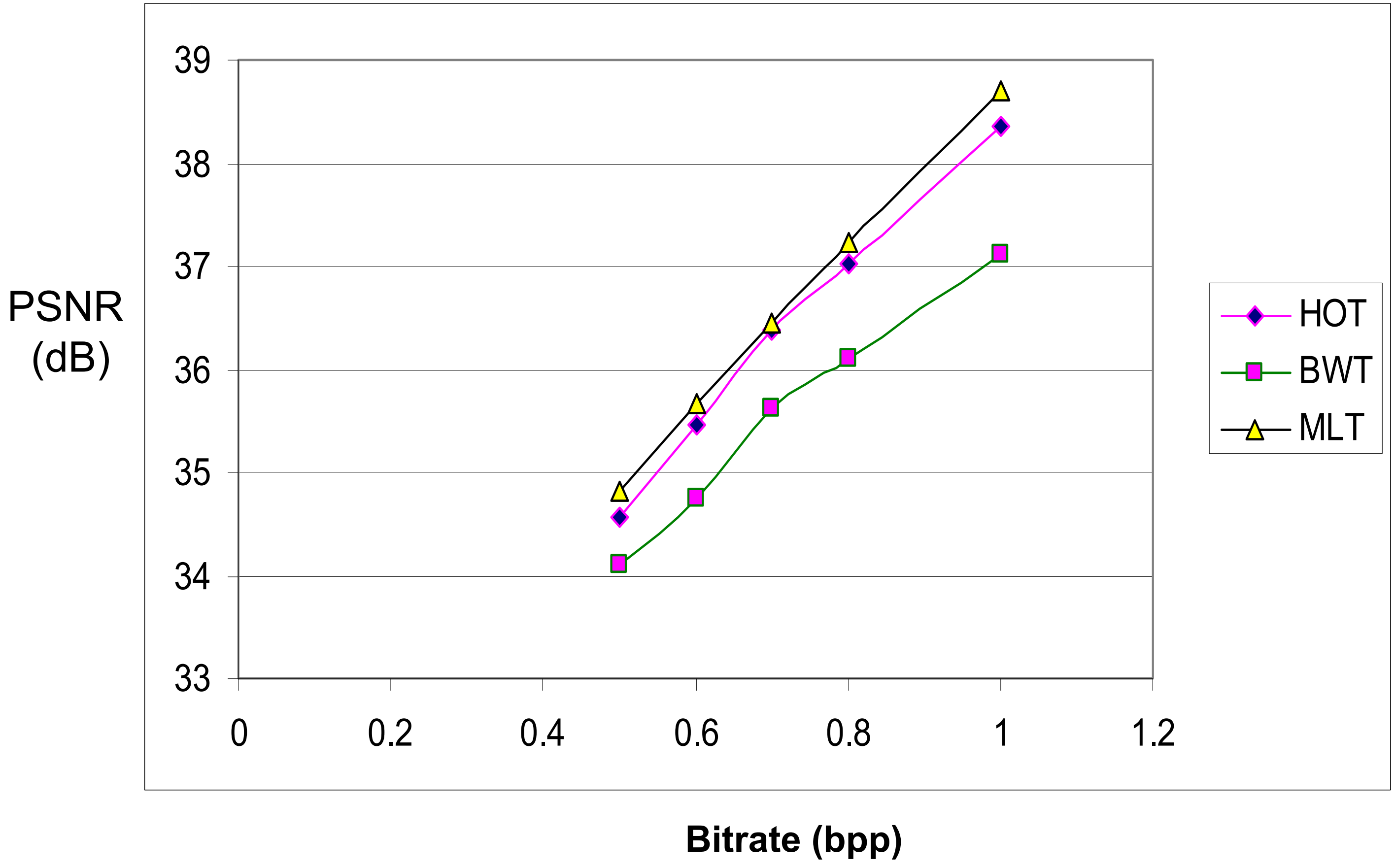


13.34:1 BWT

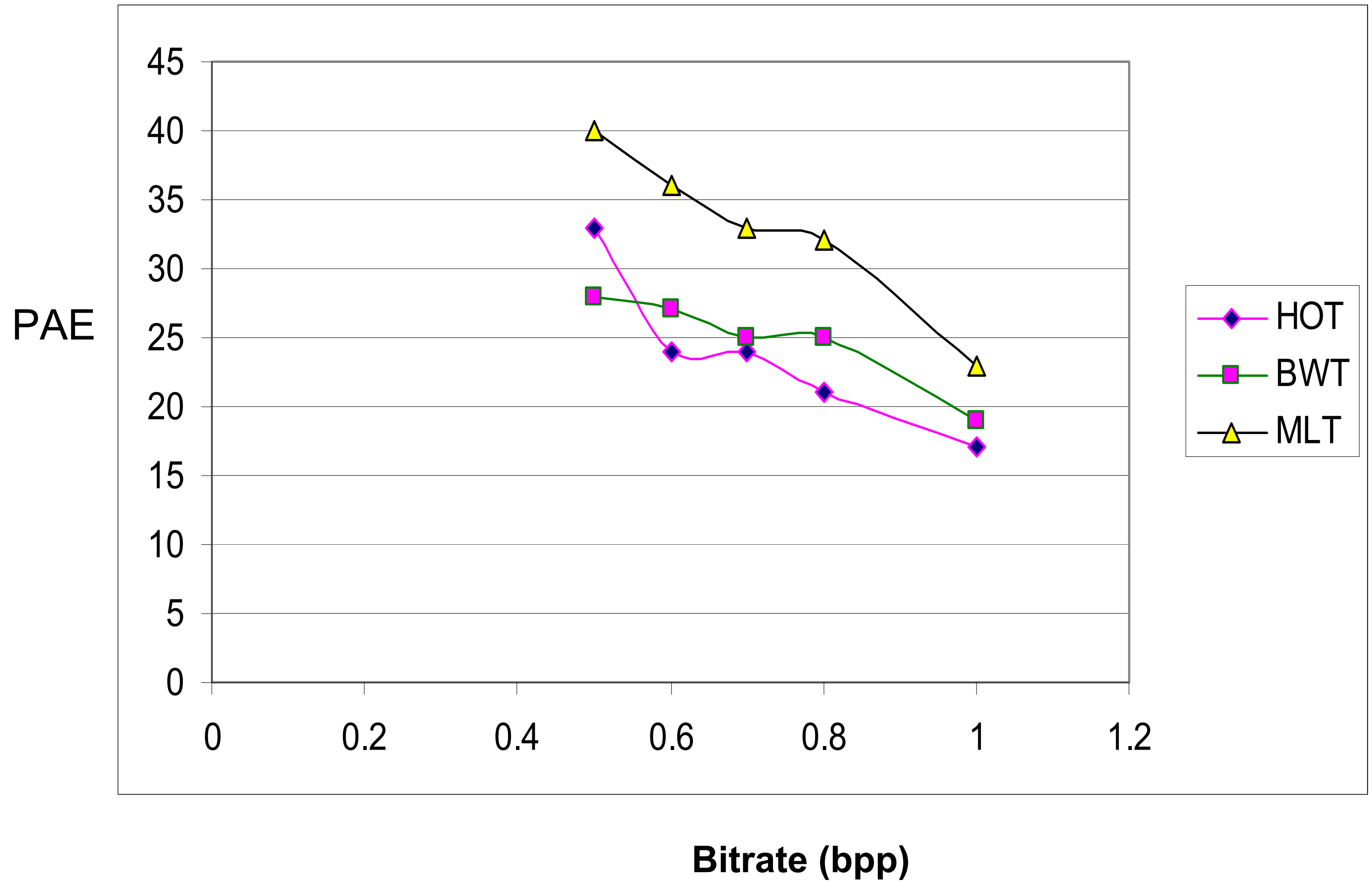


13.34:1 HOT

# Comparison of HOT and BWT Pyramids to MLT (Sample image: DMSP)



# Comparison of HOT and BWT Pyramids to MLT (Sample image: DMSP)

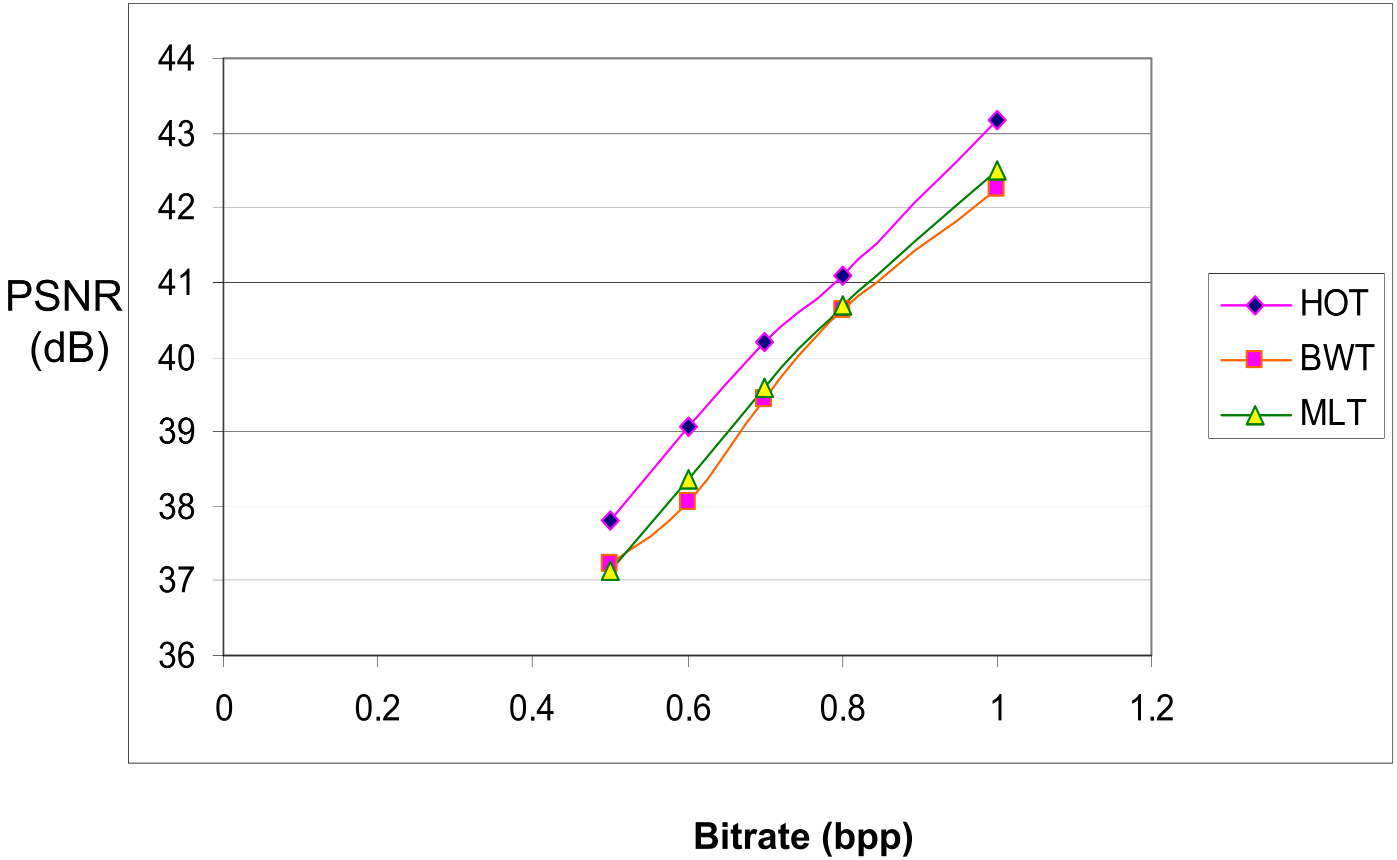


# Comparison of HOT Pyramid to BWT Pyramid

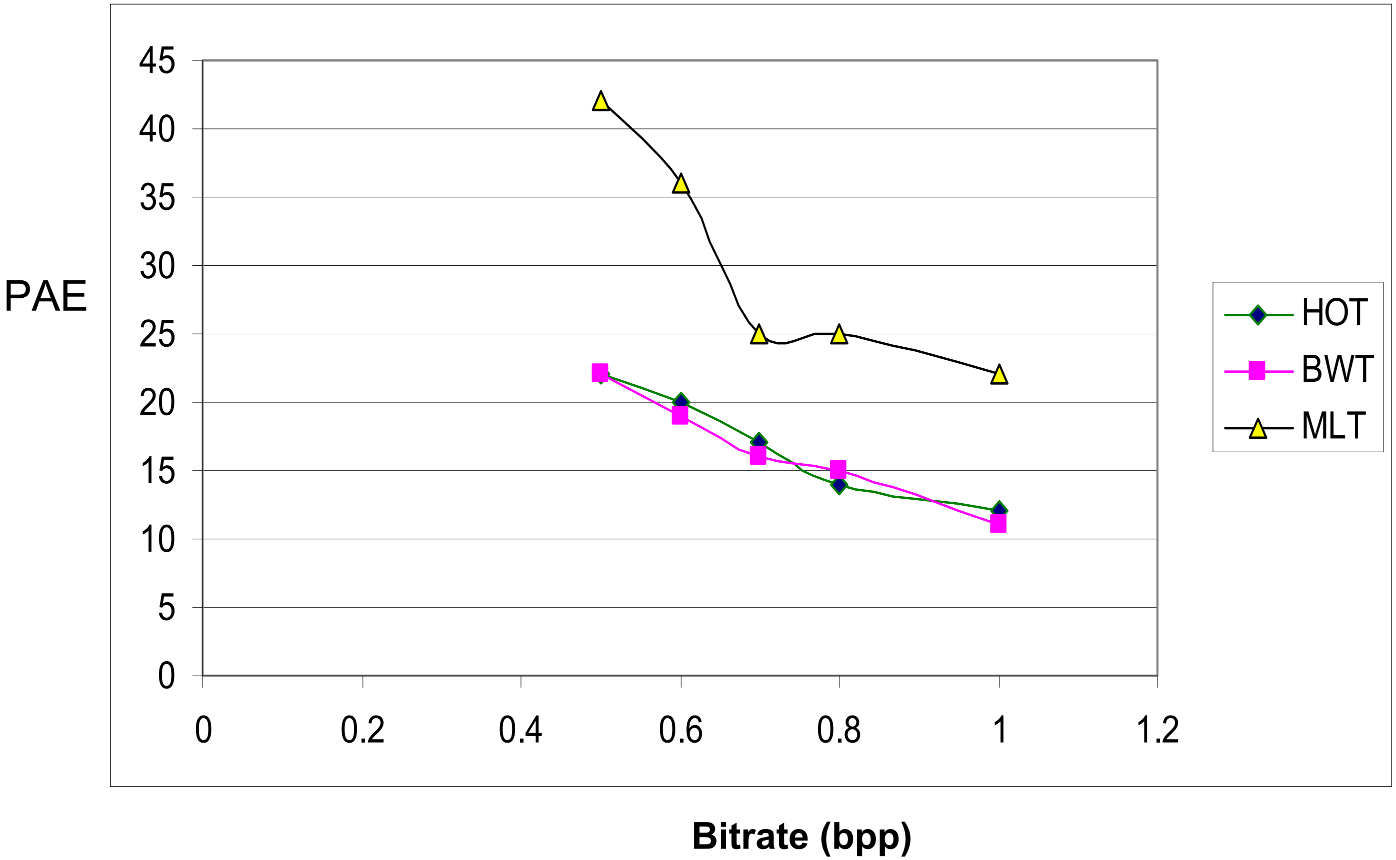
16:1 BWT

16:1 HOT

# Comparison of HOT and BWT Pyramids to MLT (Sample image: Boy)



# Comparison of HOT and BWT Pyramids to MLT (Sample image: Boy)



# Comparison of HOT and BWT Pyramids to MLT in Image Data Compression Simulations

( All test images are 8 bpp and 512 by 512 size.
All compression ratios are 10:1 )

| *metrics\images* | Lena | mount | newrv | newrr | chan4 |
|---|---|---|---|---|---|
| (1) *Root-Mean-Squared Error (RMSE)* | | | | | |
| **HOT**(+2BWT) | 2.96 | 2.35 | 4.33 | 1.76 | 1.40 |
| **BWT**(3LBWT) | 3.46 | 2.52 | 4.66 | 1.98 | 1.48 |
| **MLT** | **2.94** | **2.23** | **4.10** | **1.74** | **1.34** |
| (2) *Peak Signal-to-Noise Ratio (PSNR) in dB* | | | | | |
| **HOT**(+2BWT) | 38.70 | 40.76 | 35.40 | 43.23 | 45.23 |
| **BWT**(3LBWT) | 37.35 | 40.09 | 34.75 | 42.18 | 44.71 |
| **MLT** | **38.77** | **41.15** | **35.87** | **43.34** | **45.61** |
| (3) *Peak Absolute Error (PAE)* | | | | | |
| **HOT**(+2BWT) | **18** | **13** | **25** | **12** | **8** |
| **BWT**(3LBWT) | **18** | **13** | 26 | 13 | 9 |
| **MLT** | 22 | 18 | 46 | 17 | 9 |

# Letter Grades of Overall Quality
## (Based on 2D lossy compression of 10 images)

| | BWT | MLT | HOT |
|---|---|---|---|
| *Global* | B(blurring) | A | A |
| *Local* | A | B(large PAE) | A |

# Future Work

- Using the lossy HOT pyramid to compress ABS simulated AIRS data and real HES data.
- Using the lossless HOT pyramid to compress ABS simulated AIRS data and real HES data.
- Compare the corresponding results obtained from both lossy and lossless HOT pyramids with those from the BWT pyramid.
- Continue to investigate better lossless data compression techniques for sounder data.